Dynamic Performance Validation in the Western Power System

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Presented on behalf of the WSCC Performance Validation Task Force at the APEx 2000 in Kananaskis, Alberta in October 2000.

Abstract: Accurate knowledge and prediction of system behavior is essential to the reliable and economic operation of large power systems. This paper describes the efforts underway to meet this need in the western system.

Keywords: power transmission, system dynamics, wide area measurements, performance monitors, model validation.

1.0 Introduction

Restructuring of the electrical industry has produced considerable turmoil and uncertainty. One fact emerges very clearly, however: information, in all its forms, is the key to the reliable and economic performance of large power systems [1,2].

Information needs of the western North America power system are especially demanding. Loose interconnections and long transmission paths produce dynamic interactions that strongly couple generators in Alberta and British Columbia to those in the desert southwest, some 2800 km away. Fig. 1 indicates overall system geography, plus "index" generators for the more important interactions.

This topology has made dynamic oscillations a recurring problem in the western system. In recent years these have included elements of voltage collapse, due in part to a physical plant that has not kept pace with load growth. Other contributing factors include operating the system in unexpected ways, and system behavior that is not well captured by the models used in planning and operation studies.

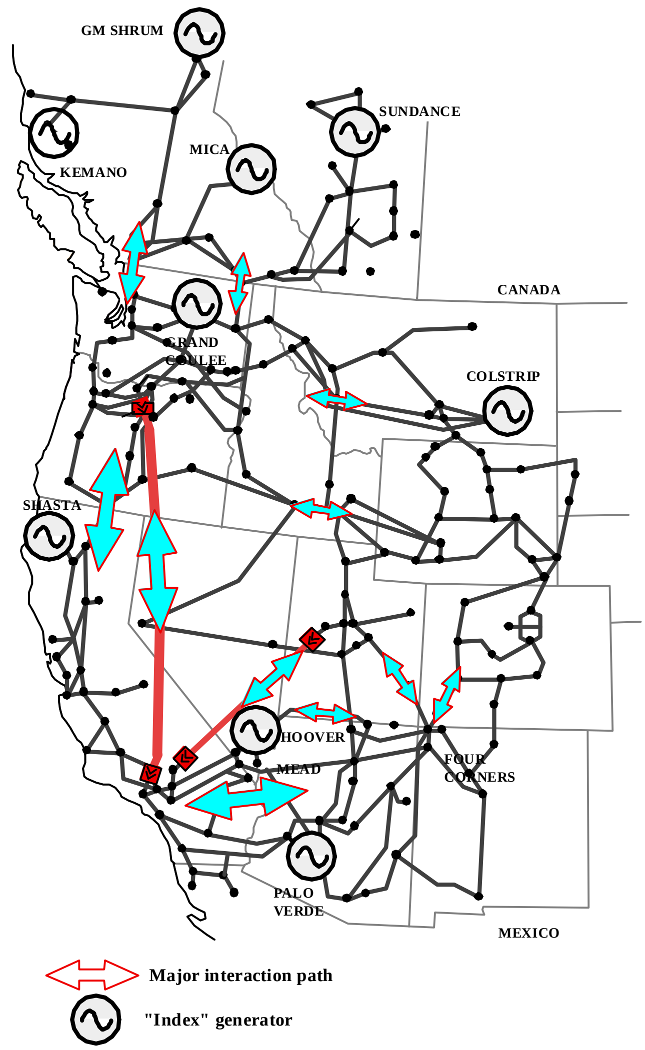

Fig. 1. Dynamic interactions in the western North America power system.

Fig. 2 provides a conspicuous example of this. The upper trace shows recorded western system

[1] Operated for the U.S. Department of Energy by Battelle Memorial Institute under contract DE-AC06-76RLO 1830.

behavior in the breakup of August 10, 1996. The lower trace shows predicted behavior based upon standard planning models of the time [3]. Though the models have undergone major improvements since that time, the power system itself remains fully capable of producing enigmatic and disruptive surprises.

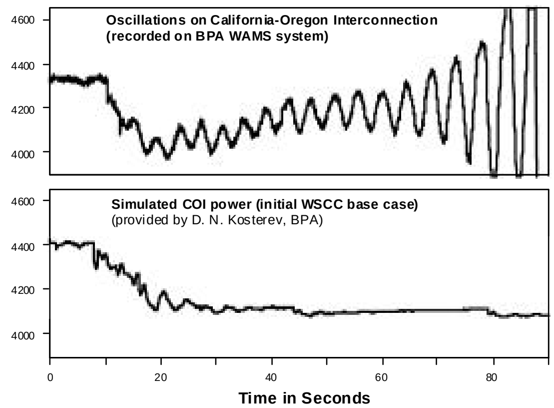

Fig. 2. Initial modeling failure for WSCC breakup of August 10, 1996.

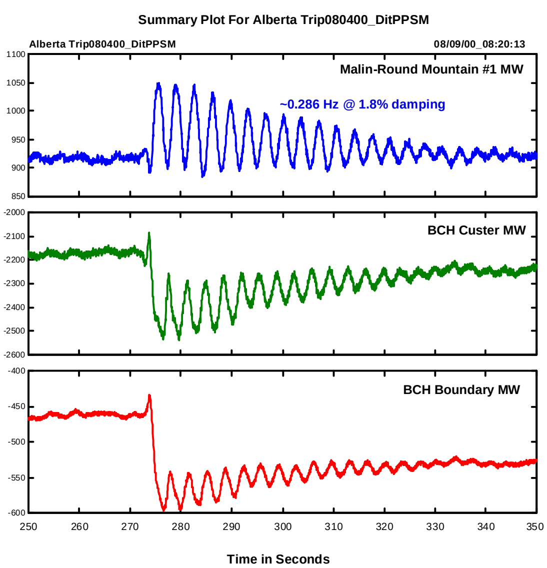

Fig. 3. Alberta separation of August 4, 2000

One of these surprises happened when Alberta separated from the main grid on August 4, 2000. As indicated in Fig. 3, this triggered poorly damped oscillations of the north-south swing mode associated with the Pacific AC Intertie (**PACI**). This is the same mode that broke up the system on August 10, 1996.

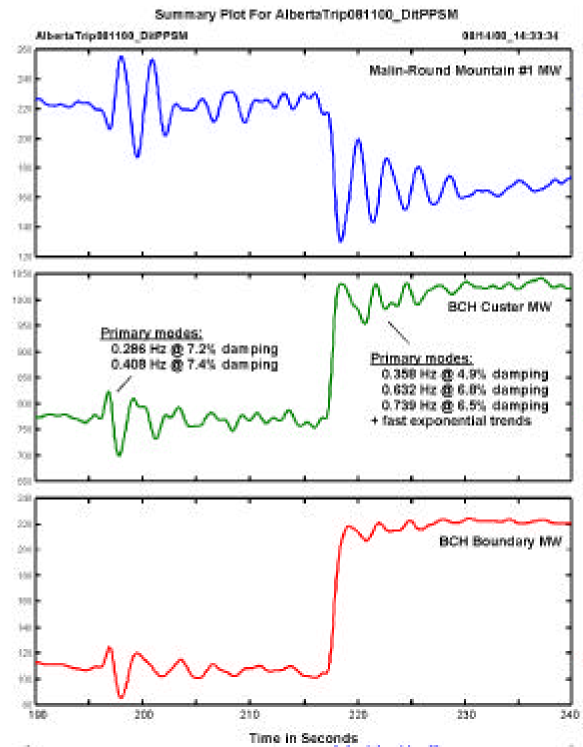

Fig. 4. Alberta separation of August 11, 2000.

Just a week later Alberta separated again, with an open-reclose-open sequence of breaker operations. System response, shown in Fig. 4, was well damped and consistent with usual behavior. The first ringdown, following successful reclosure of the connection to Alberta, produced oscillations of the PACI mode (0.286 Hz) plus the Alberta mode (0.408 Hz). For the second ringdown Alberta had separated from the system. The Alberta mode was not present, and the PACI mode had shifted upward to 0.358 Hz. Other modes present appear to be Kemano (0.632 Hz) and the N. California-Arizona mode (0.739 Hz). These are initial findings that may be modified as the WSCC utilities continue their examination of the Alberta separations.

The western utilities, working together via the Western Systems Coordinating Council (WSCC), have examined many such events over the years. The outcome has been progressive improvement of planning resources and practices, following a pattern that is loosely indicated in Fig. 5.

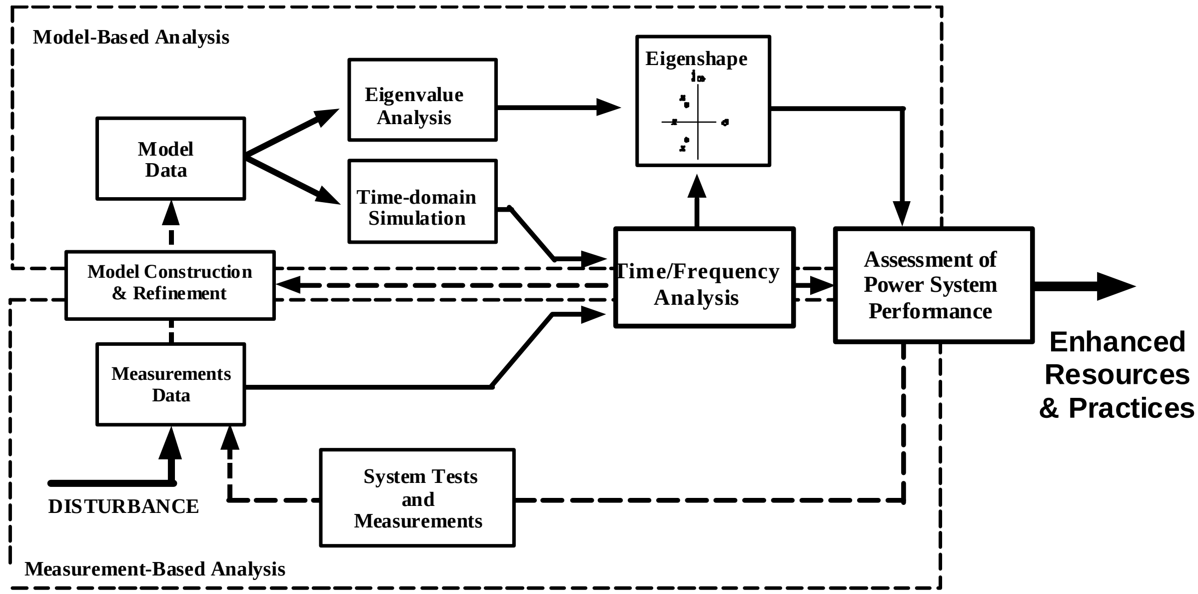

Fig. 5. Model refinement process based upon observed power system performance

2.0 Performance Measurements in the WSCC

Like the power system itself, the resources for the performance validation process are hard pressed to keep up with the challenges of utility restructuring. The more advanced toolsets are in shorter supply than in earlier years, and the engineers to use them are heavily involved with a far busier system. As usual, though, teamwork among the member utilities is producing effective solutions.

Notable progress is being made in two highly important areas. These are the deployment of a WSCC Wide Area Measurement System (**WAMS**), and an evolving WSCC program for using WAMS in an ongoing validation of system dynamic performance.

Much of the dynamic behavior of the western system is routinely captured on "backbone" facilities of WSCC WAMS. This backbone consists of two general networks:

- ***A distributed network of local monitors*** that record analog signals from control systems, conventional transducers, or other analog devices.
- ***A centralized phasor measurements network*** in which precisely synchronized digital transducers (**PMUs**) are linked to phasor data concentrators (**PDC**s) by real-time digital communication channels.

Both networks are configured and operated so that recording is effectively continuous. A common set of time/frequency analysis tools (Fig. 5) accommodates data from both networks, and from the model simulation codes used in system planning.

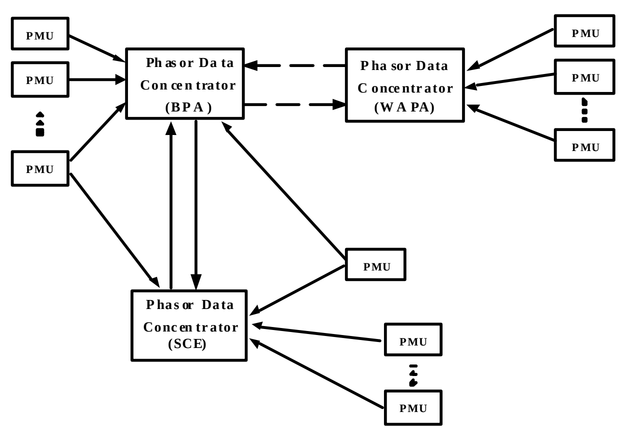

Fig. 6. Partial topology of the emerging WSCC phasor measurements network

Deployment of the WSCC phasor network is proceeding along the lines indicated in Fig. 6. Fully operational PDC units are located at the Bonneville Power Administration (**BPA**), Southern California Edison (**SCE**), and the Western Area Power Administration (**WAPA**). Other utilities are providing PMU signals to these concentrators, and still others are deploying similar PDC-based networks in their own service areas. Extension of the WAMS Backbone into British Columbia and Alberta is especially critical to tracking dynamic performance of the overall system.

3.0 Approaches to Performance Validation

Planning models are essential for interpreting observed system behavior, and for predicting future behavior under assumed conditions. Continual refinement of models and practices is essential to a robust planning process and, ultimately, to overall power system reliability.

Benchmark data for model validation can be obtained from ambient behavior, chance disturbances, or staged tests (Fig. 7). All of these have their merits, and they are used in combination. Support for this has been a primary driver for development of WAMS technology and the WSCC WAMS backbone [4-7].

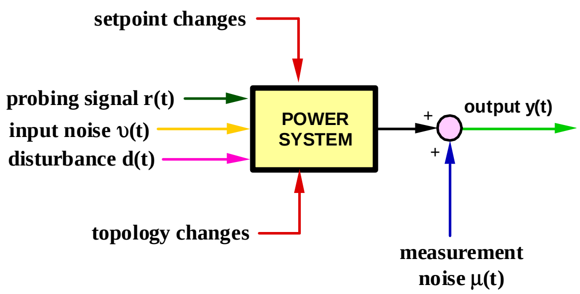

Fig. 7. Information sources for system performance validation

Validation tests drawing upon the WSCC phasor network were performed on the following dates:

- September 4, 1997
- April 27, 1999
- June 7, 2000

The tests became more comprehensive as the phasor network matured. Notably, the two most recent tests resumed and improved upon HVDC probing procedures that had not been used since 1985.

4.0 The Validation Tests of June 7, 2000

Primary elements of the June 7 tests were the following:

- **Correlation analysis** of ambient behavior before and after the test.
- **SCADA "Snapshots"** of system conditions at critical points in the test sequence.
- **Staged generator trips**, with automatic generation control (AGC) and other controls suspended.
- **Insertions of BPA's 1400 MW Chief Joseph dynamic brake**.
- **Mid-level probing** (±125 MW) of individual oscillation modes by HVDC modulation at the Celilo terminal of the Pacific HVDC Intertie (**PDCI**).
- **Low-level broadband probing** (±20 MW) by HVDC modulation at the Celilo terminal of the PDCI.

The June 7 tests were planned and coordinated by the Performance Validation Task Force (**PVTF**) of the WSCC Modeling and Validation Work Group (**M&VWG**). Comparison and calibration of planning models against test results are just begun, and progress in this will be reported by the PVTF. PNNL support for this work is provided under a WAMS Outreach activity of the US Department of Energy [6].

The remainder of this Section provides some results from the PVTF measurements analysis to this point, plus comparative results from earlier tests.

4.1. Ambient Noise Analysis

Power flowing on major WSCC interconnections contain small random fluctuations that reflect system response to random load switching and other low level stimuli. Spectral analysis of this ambient "noise" provides useful signature information about dynamic conditions.

Fig. 8 indicates that dynamic conditions did not change very much during the test period. Activity of the Alberta mode (near 0.4 Hz) may have been somewhat less than usual, and there seems to have been some intermittent activity near 1.1 Hz.

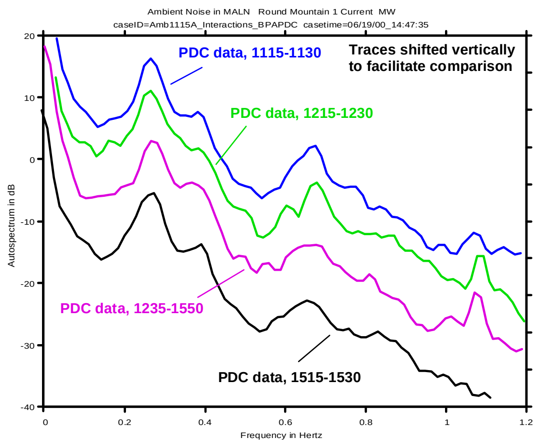

Fig. 8. Spectral content of the Malin-Round Mountain MW signal, before and after the model validation test on June 7, 2000

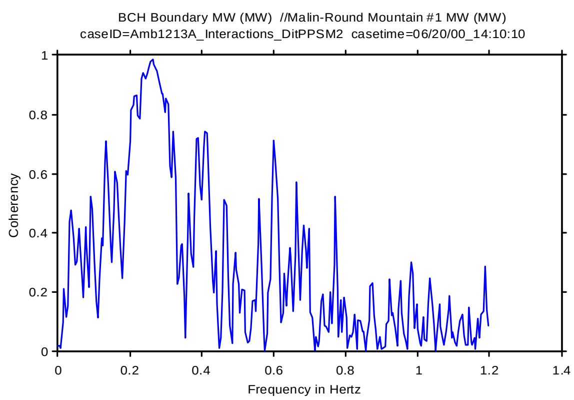

Fig. 9. Correlation of BCH Boundary MW against Malin-Round Mountain MW (Dittmer PPSM, 1215-1230 PM)

Fig. 9 shows a high resolution coherency spectrum obtained by correlating fluctuations on the Boundary circuits against fluctuations on the PACI at Malin. There is evidence to the effect that some or all of the peaks in this figure represent swing mode frequencies.

4.2. Brake Insertions

Fig. 10 through Fig. 12, for the earlier test in 1997, provide comparative historical data relative to the June 7 tests. These figures show the strong influence that status of the Alberta interconnection has in ringdown signatures for brake insertions.

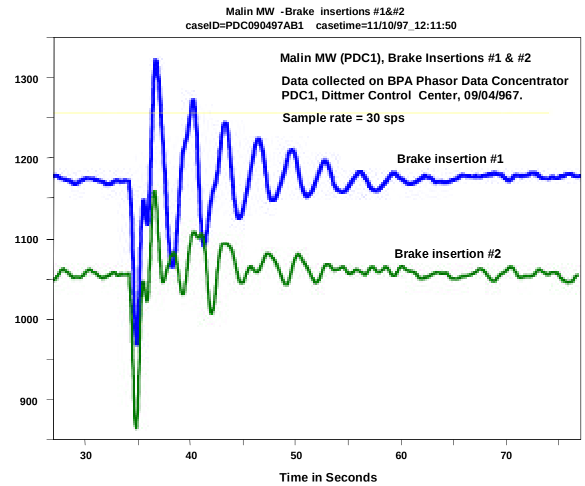

Fig. 10. Effect of TransAlta line upon PACI ringdown. Brake insertions #1 and #2 on 09/04/97.

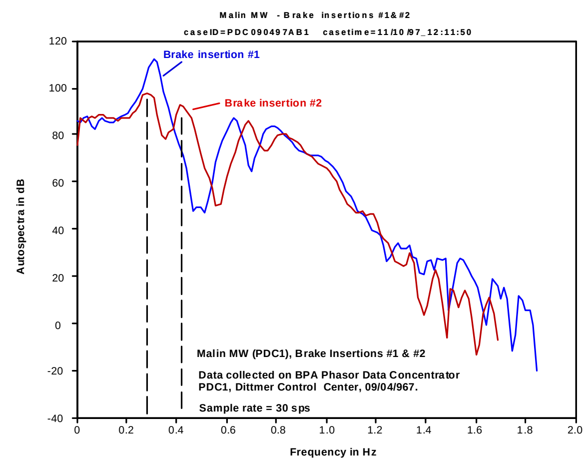

Fig. 11. Effect of TransAlta line upon PACI ringdown spectrum. Brake insertions #1 and #2 on 09/04/97.

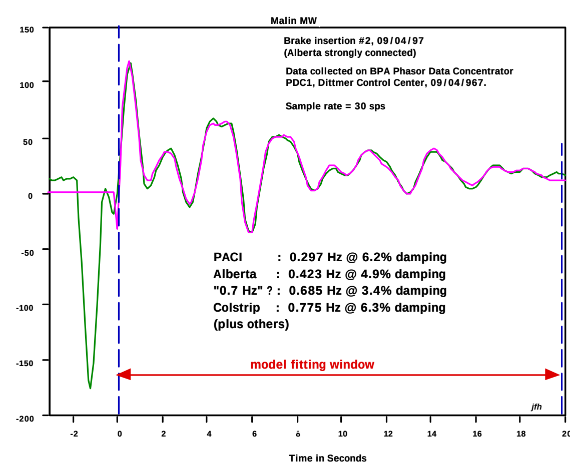

Fig. 12. Primary modes for initial Prony fit to brake insertion #2, 09/04/97.

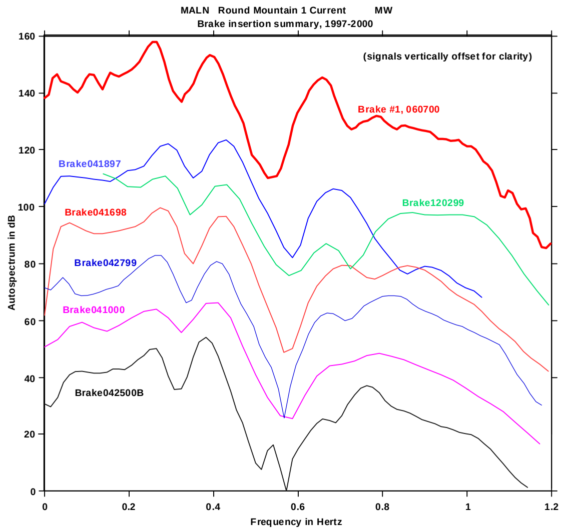

Fig. 13. Ringdown signature of brake test insertion #1 vs. historical records

Fig. 13 shows that the ringdown signature on June 7 fits into the general pattern for Alberta strongly connected, though response near 0.7 Hz may be somewhat stronger than usual.

4.3. HVDC Probing

Fig. 14 provides an overview of the HVDC probing signals used on June 7. The tests involved two sessions of low-level broadband noise probing plus five mid-level probing events for single modes.

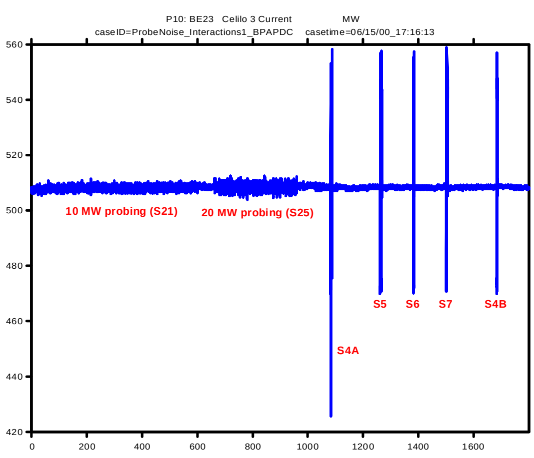

Fig. 14. Response of Big Eddy –Celilo 230 MW to HVDC probing signals.

Fig. 15 shows a typical response for mid-level single mode probing. By design, the level of stimulus is close to the necessary minimum for assessing mode damping from a single ringdown.

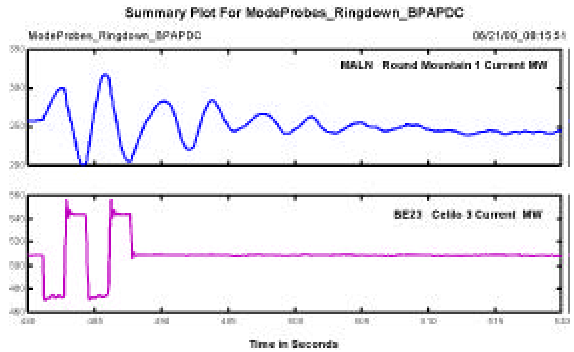

Fig. 15. Ringdowns for 2 cycle HVDC probing at 0.33 Hz.

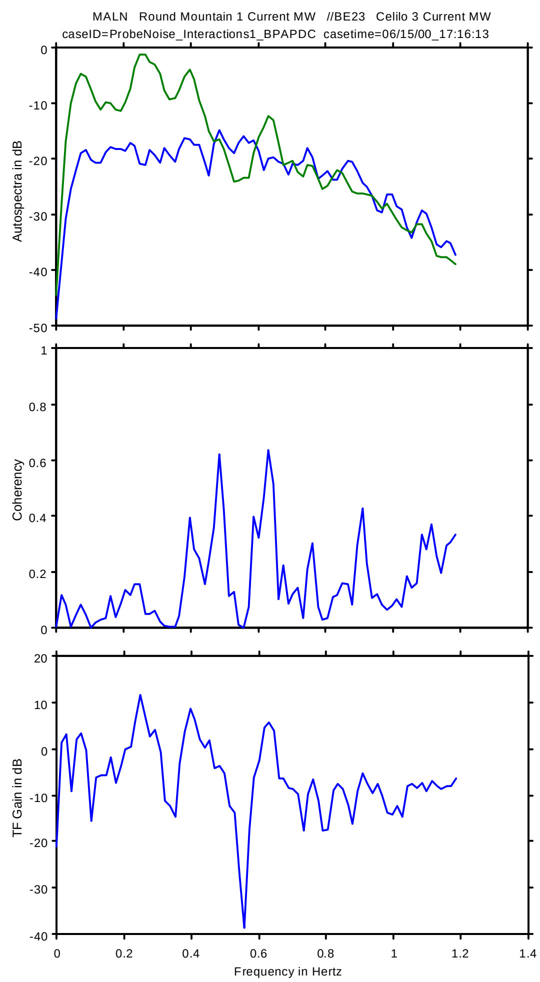

Fig. 16. Correlation of Malin-Round Mountain MW against Celilo 230 feeder MW (BPA PDC, ±20 MW noise probing)

The results in Fig. 16 represent a different approach, and somewhat different objectives, In this method the stimulus is much lower, but response is averaged across a probing interval that is much longer (five minutes in the present case). The stimulus is sufficiently broadband to examine all interarea modes, and possibly to examine internal dynamics of the PDCI system itself. Use of this method on June 7 was exploratory, and the stimulus will likely be expanded somewhat in later tests.

5.0 Conclusions

This paper has described ongoing WSCC efforts to meet the dynamic information needs of the western power system. Special attention has been given to progress in the deployment of WSCC WAMS, and to the use of WAMS in an ongoing validation of system dynamic performance.

More extensive materials on WSCC monitor facilities are being developed by the WSCC Disturbance Monitoring Work Group, in response to the requirements and the intent of disturbance monitoring standards issued by the National Energy Regulatory Commission (**NERC**).By way of example, the paper has also provided recent results from the validation effort. The interpretation and analysis of these results is preliminary, and may be adjusted on the basis of later findings by the PVTF.

6.0 Acknowledgments

The authors wish to acknowledge to all of the members of the WSCC Performance Validation Task Force and the many other WSCC groups who contributed and continue to contribute to the WSCC performance validation efforts.

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Biographies

Dynamic Performance Validation in the Western Power System • John F. Hauer

Mr. Hauer will discuss ongoing efforts of the Western Systems Coordinating Council (**WSCC**) to meet information needs of the western power system. Special attention will be given to progress in the deployment of a Wide Area Measurement System (**WAMS**) spanning the grid, and to the use of WSCC WAMS in an ongoing validation of system dynamic performance. Examples of this include the performance validation tests of June 7, 2000, and system oscillations triggered by the Alberta separation of August 4, 2000. The interpretation and analysis of these results is preliminary, and may be adjusted on the basis of later findings by the Performance Validation Task Force. Related materials, prepared by the WSCC Disturbance Monitoring Work Group, build upon WSCC WAMS to meet he requirements and the intent of disturbance monitoring standards issued by the National Energy Regulatory Commission (**NERC**).

Mr. Hauer is a senior staff scientist at the Pacific Northwest National Laboratory in Richland, Washington. Prior to this he was the Principal Engineer for Power System Dynamics at the Bonneville Power Administration in Portland, Oregon. Since 1975 he has been strongly involved with matters affecting the reliability and performance of large power systems, and has specialized in the direct examination of western system dynamic behavior. WSCC WAMS is one consequence of that involvement. Mr. Hauer is an active participant in related WSCC and professional society work groups, and has authored or contributed to many writings on power system analysis and control. He was a member of the U. S. Department of Energy Power Outage Study Team, established by the Secretary of Energy to examine and report on reliability events that occurred in the eastern United States during the summer of 1999.